

## **FEEDWATER HEATER TUBE SLEEVING**

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### **Abstract**

This paper describes utility experience with a tube sleeving technique used for extending the remaining life of two heaters that have been rapidly degrading.

Waterside Unit 80 experienced numerous forced outages and de-rating incidents due to tube leaks in the two Heaters #81E and 82W. Root cause analysis was performed using eddy current testing and remote video inspections. The tube leaks were attributed to Stress Corrosion Cracking (SCC) of the Alloy 400 tubing in two specific locations: (1) the tubesheet area, and (2) the U-bends.

The sleeves (thin-walled tubes) were inserted and hydraulically expanded on the inside surface of the tube in the tubesheet area. The nine-inch long sleeves had covered the specific location where the tubes were susceptible to SCC. Sleeves were installed as a preventive measure in tubes that have not yet cracked. As a result of the sleeving, the parent tube metal in that area no longer experienced the chemical environment of the feedwater. This prevented crack initiation in that area. Additionally, a few tubes having pinhole leaks were also sleeved and returned to service instead of the usual practice of plugging the leaking tubes.

Following are the conclusions based on monitoring of the heaters after sleeving (over a two-year period for Heater #81E and one-year period for Heater #82W):

1. Sleeving has been demonstrated as a cost-effective repair technique for preventing the tubesheet area SCC in Alloy 400 tubed feedwater heaters. This preventive measure has extended the life of the heaters and avoided the need for their replacement.
2. In the two heaters, 81E and 82W, the sleeving has successfully prevented SCC cracking in the tubesheet area. None of the tubes have leaked in this location after sleeving. Sleeving has improved reliability of the Unit by preventing forced outages/deratings. Additionally, the maintenance cost associated with unplanned repairs due to tube leaks has been avoided.
3. Tubes with small cracks or pinhole leaks in the tubesheet area can be sleeved instead of plugging the tubes. Tubes may then be returned to service despite small cracks or pinhole leaks. The usual practice of plugging increases flow rates in other tubes, accelerates further damage and reduces heat transfer performance whereas sleeving extends the remaining life of the heater.

4. A limitation of the sleeving technique is that the sleeves cannot be installed in the U-bend area. Subsequent to the sleeving, a few tubes in both heaters experienced leaks at the U-bends. Another remedy, plugging the tubes with short radius U-bends, was implemented to mitigate the leaks in Heater # 81E. The two heaters are currently providing leak-free service after the sleeving and plugging techniques were implemented.

**Introduction**

Alloy 400 (a Nickel – Copper alloy) has been the preferred tube material for High Pressure (HP) feedwater heaters because of its excellent corrosion resistance and high temperature strength. Most heaters with Alloy 400 tubing have a service life as long as 35 years; however, some of the heaters have a very short life. For example, Hudson Avenue 10 HP Heater needed a replacement in 1992 after only four and a half years of service. Root cause for this premature failure was identified as stress corrosion cracking (SCC). When the results of Con Edison’s root cause analysis were published (Reference 1), engineers from several utilities confirmed that they also experienced similar premature failures. Susceptibility of Alloy 400 tubing to SCC failures was identified as a generic problem for heaters with Alloy 400 tubing. An EPRI survey has determined that 6% of the population of heaters with Alloy 400 tubing are susceptible to this mechanism and the other 94% provide longer service life.

Waterside Heaters #81E and 82W had numerous tubes plugged after only seven years of service. Further damage to the tubes from this mechanism was accelerating rapidly (Figure 6). Considering that more than 10% of the tubes were already plugged and the Unit was experiencing too many forced outages / deratings, both of these heaters were considered candidates for replacement. This Project was undertaken to stop further tube degradation, extend the heaters’ remaining useful life, and avoid the replacement costs. Root cause analysis was performed on these two heaters using eddy current testing, remote video examination of the tube inner surface, and laboratory examination of pulled tubes. These investigations demonstrated that the tubes were leaking due to SCC in the tubesheet area.

**HEATER DATA**

	<b>81E</b>	<b>82W</b>
Procurement	1992	1992
Installation	1994	1994
Tube	Alloy 400	Alloy 400
Feedwater Pressure	2,000 PSIG	2,000 PSIG
Steam Inlet Pressure	405 PSIA	210 PSIA
Steam Inlet Temperature	618 F	468F

## **SLEEVING TECHNIQUE**

Sleeving has been widely used in low-pressure heat exchangers (such as condensers); however its application in high-pressure feedwater heaters is recent because of the difficulty in achieving a leak-free joint in high-pressure heaters. Florida Power & Light Co and TVA have successfully used sleeving in feedwater heaters.

The tooling was fabricated for the specific requirements of the subject heaters. Thin walled sleeves (nine inches long tubes with 0.020" wall thickness) were installed on the inside surface of the tubes. The flare on the sleeves was designed to prevent the sleeve from accidentally slipping into the vertical tubes in these vertical heaters with the channel head on top.

The sleeve material was 90-10 Copper-Nickel, which is not susceptible to the tubesheet area SCC unlike the parent tube material, Alloy 400. Possibility of galvanic corrosion due to having dissimilar metals is unlikely because these two materials have the same potential in the galvanic series and therefore they are compatible with each other (Reference 2).

The sleeves were installed on the tube inner surface over the susceptible area using a hybrid hydraulic – mechanical expansion. The hydraulic expansion of the entire length of the thin walled sleeve was performed using tools that have displacement control. This dimensional control allows the sleeve material to conform to the ID surface of the parent material without inducing deformation, enlargement or ballooning of the parent tube material. To provide the leak-tight joint, mechanical rollers hard-rolled the sleeves in the tubesheet area, and displacement controlled mechanical expanders enlarged the other ends of the sleeves.

The sleeving will (1) prevent crack initiation in undamaged tubes, and (2) cover small cracks / pinholes with a tight seal. Tubes with small leaks may be returned to service with this technique. However, many of the previously leaking tubes were explosively plugged, a process that has already induced heavy deformation of the tubes in the tubesheet area. Therefore, no attempt was made to remove the plugs for the sleeving process. At the time of sleeving, four tubes in Heater 81E and one tube in 82W were known to be newly leaking, and these tubes were sleeved and returned to service.

### **Effectiveness of Sleeving**

The sleeving was implemented in two phases: Heater #81E was sleeved during the Fall 2001, and Heater #82E in Fall 2002.

During the period from 2001 to 2004, the sleeving technique was successful in completely preventing the tubesheet area leaks in both heaters. However, these two heaters developed a few new tube leaks in a different location, the U-Bends. Prior to the sleeving, these heaters were susceptible to leaks in both the tubesheet area and the U-

bends. Videoprobe inspections confirmed that all of the recent leaks were in the U-Bend area, and none of the sleeved tubes had leaked in the tubesheet area.

Two leaking tubes were plugged in 81E feedwater heater during the Spring 2003 firm up outage. These leaks became apparent during a maximum load/ramp rate test requested by System Operations just prior to the start of the Spring 2003 firm up outage. There had been no indication prior to this test that leaks were present in the heater.

All of the new leaks occurred in the heaters' U-Bend areas after the tubes were sleeved in the tubesheet area and were confined to the first three rows. These rows had sharp radius U-Bends that have relatively more deformation and residual stress during heater fabrication. The U-Bend leaks occurred despite having the bends stress relieved during heater fabrication as a preventive measure against U-Bend leaks.

The first three rows of #81E were preventively plugged in Spring 2003, and this heater experienced no further leaks since then. Waterside Station has a contingency plan to plug the first three rows in the other Heater, #82W if U-Bend leaks occur again. However, this heater has had no new tubes leaks since having two U-Bend leaks in Spring 2003.

Four tubes in #81E and one tube in #82W were sleeved with known pinhole leaks in the tubesheet area. These tubes have not leaked in subsequent operation. sleeving is demonstrated to be an acceptable alternative to plugging the tubes with pinhole leaks. Sleeved tubes, unlike the plugged ones, remained in service and this process extended the useful life of the heater.

### **Cost / Benefit**

At the time of implementing this project, both of these heaters were candidates for immediate replacement. Each heater had more than 10% tubes placed out of service due to plugging the leaking tubes. Another consideration is that the number of leak events was rapidly increasing and further damage to the tubes was accelerating. Future operation of these heaters was highly unreliable. The tube sleeving has stopped the accumulation of further damage of tubes in the tubesheet area and eliminated the need for the replacement of the two heaters. Cost of sleeving is less than 5% of the replacement cost for these two heaters.

## Conclusions

1. Sleeving has been demonstrated as a cost-effective repair technique for preventing the tubesheet area SCC in Alloy 400 tubed feedwater heaters. This preventive measure has extended the life of the heaters and avoided the need for their replacement.
2. In the two heaters, #81E and #82W, sleeving has successfully prevented SCC cracking in the tubesheet area. None of the tubes has leaked in this location after sleeving. This has improved reliability of the Unit by preventing forced outages/deratings. Additionally, the maintenance cost associated with unplanned repairs due to tube leaks has been avoided.
3. Sleeving may be used in tubes having small cracks or pinhole leaks in the tubesheet area instead of plugging. Tubes may be returned to service despite small cracks or pinhole leaks, thus extending the remaining life of the heater.
4. A limitation of this technique is that the sleeves cannot be installed in the U-bend area. Subsequent to the sleeving, a few tubes in both heaters experienced leaks at the U-bends. Another remedy was implemented to mitigate the U-Bend leaks. Tubes with short radius U-bends were preventively plugged. The two heaters, #81E and #82W, are currently providing leak-free service after the implementation of these two measures: sleeving in the tubesheet area and preventive plugging of tubes with short radius U-Bends.

## REFERENCES

1. A. S. Amar, "Stress Corrosion Cracking of Ni-CU Alloy 400 Tubes in Feedwater Heaters", PWR-Vol.25, pp 103-107, Heat Exchanger Technologies for the Global Environment, ASME 1994.
2. L. L. Sheir, R. A. Jarman and G. T. Burstein, "Corrosion, Volume 2", Third Edition 1994, Page 21:31.

## VIDEO INSPECTION FWH 81 E PRIOR TO SLEEVING

Three leaking tubes were examined. The probe (with a 90° prism) indicated that all three tubes had cracks at the same location, 4-3/8" below the top of the tubesheet. These axial cracks were short in length, but leaked through the tube wall.



Figure 1. Leak #1 in FWH 81E



Figure 2. Leak #2 in FWH 81E



Figure 3. Leak #3 in FWH 81E

## VIDEO INSPECTION FWH 82W

One leaking tube was examined with the probe. This crack was also at the same location as in the Heater 81E leaking tubes; located at 4 3/8" below the top of the tubesheet. The leak started as a short, through-wall axial crack (like Figures 1, 2 and 3). However, as a consequence of erosion due to the leak, the crack became a rounded pinhole. Erosion on the tubesheet behind the tube can be seen through the hole.

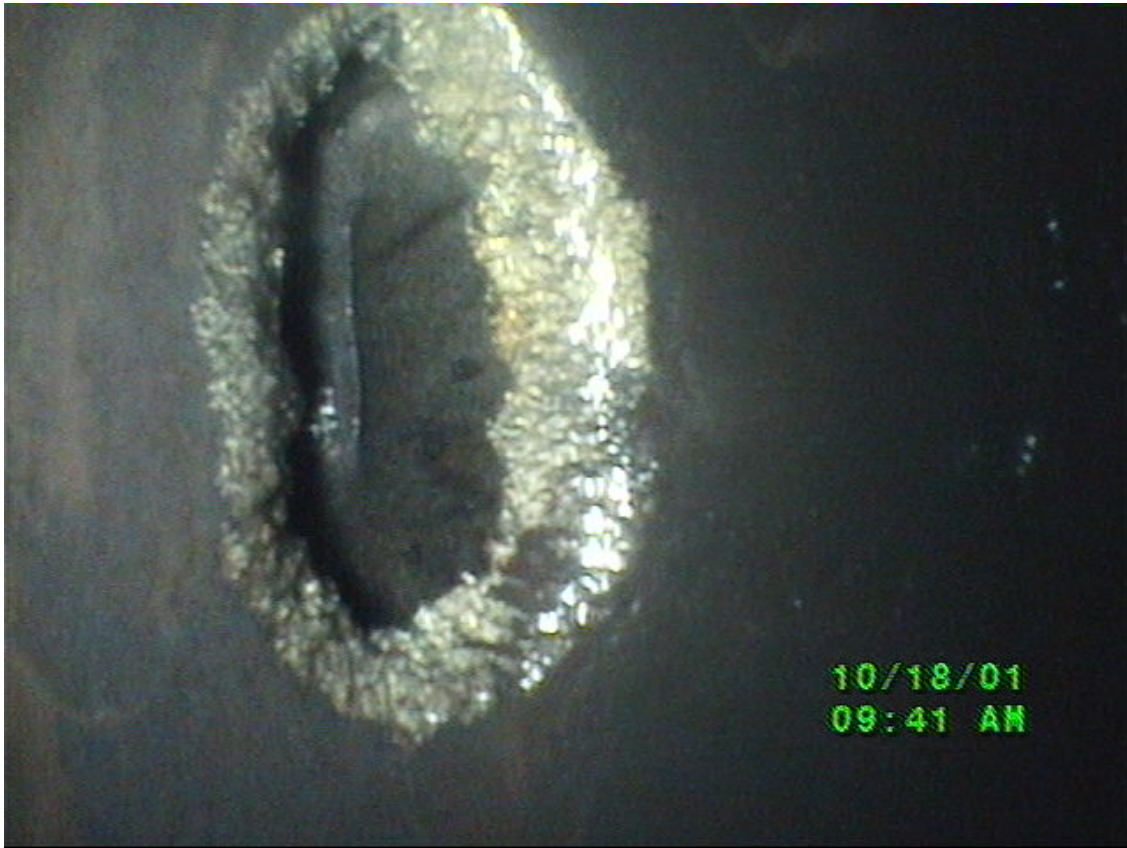


Figure 4. Leak in FWH 82W

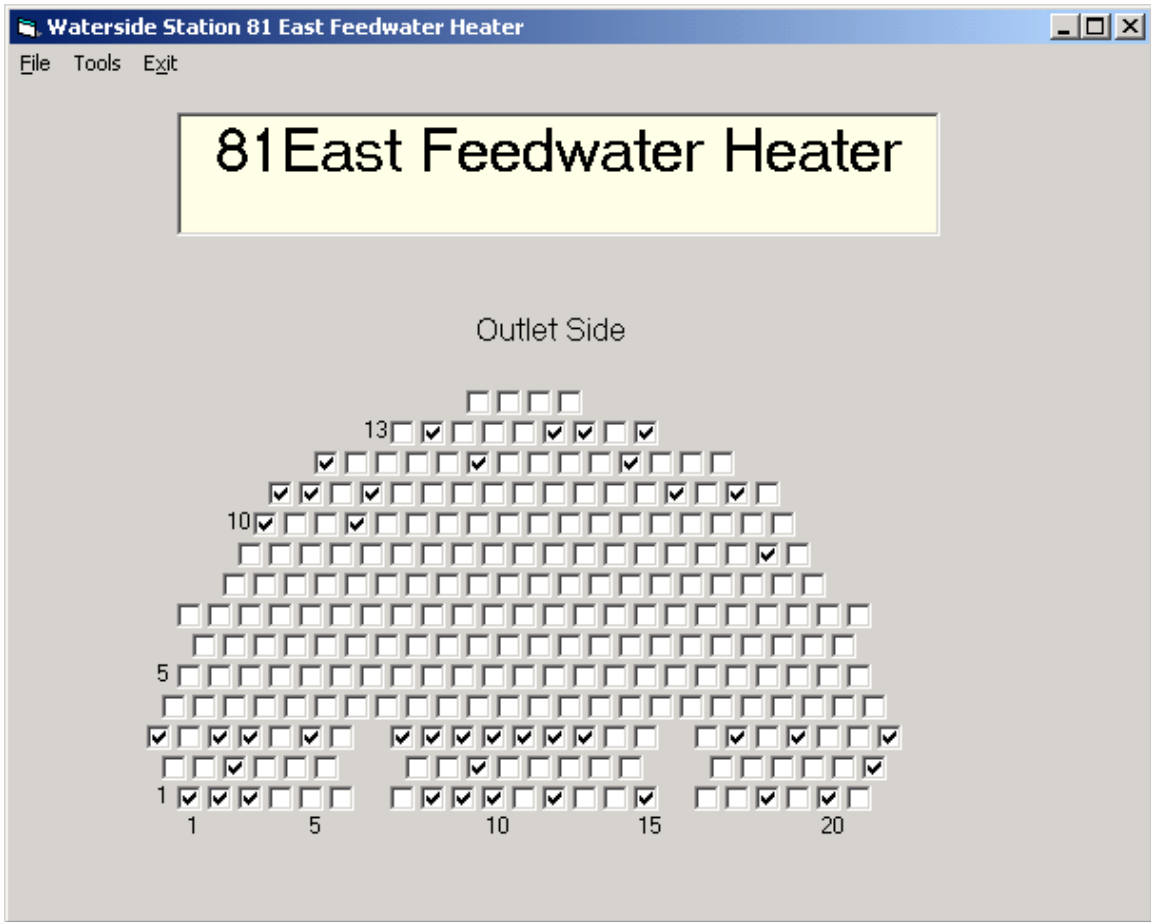


Figure 5 Tubesheet Map showing location of plugged tubes after tube sleeving.

Cumulative Damage in WS 81E Heater

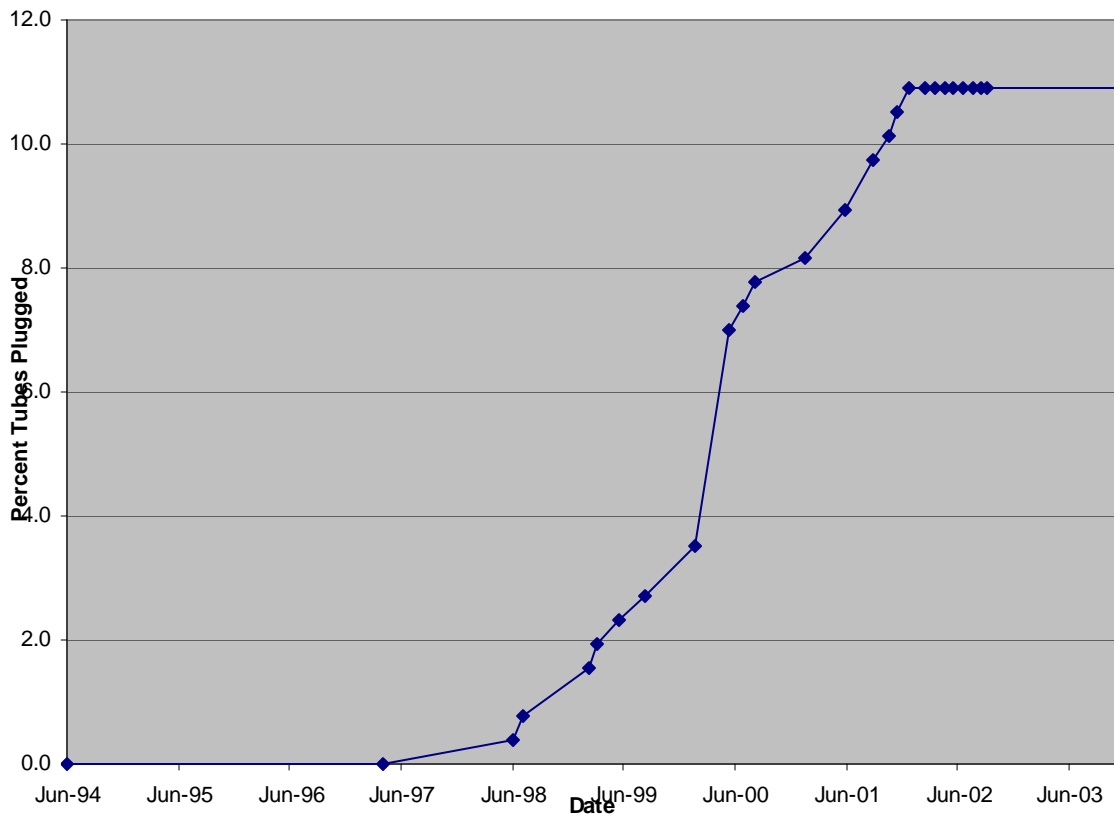


Figure 6: Plot showing the cumulative damage in the heater. After sleeving in October 2001, further damage due to tubesheet SCC was stopped. However, there were three subsequent leaks at the U-Bends. Currently, the curve is flat (no further damage accumulation) after preventing leaks at both locations.